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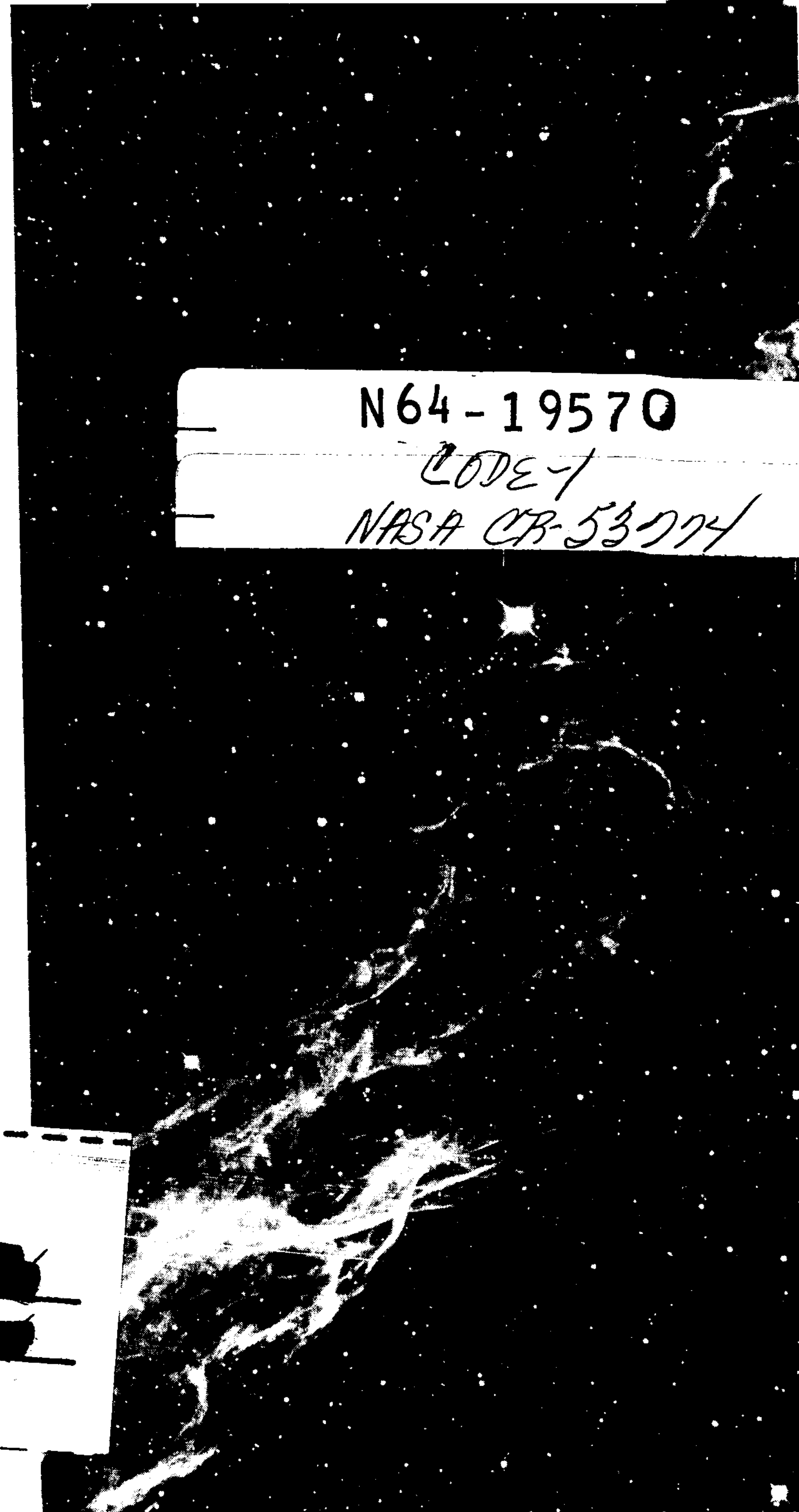

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THE ASTEROIDS

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THE ASTEROIDS

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ABSTRACT

THE ASTEROIDS

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This document reports the fourth of a series of studies being undertaken by ASC/IITRI on the Scientific Objectives of Deep Space Investigations. More than 1500 separate asteroids of magnitude down to 18 have been detected and catalogued in the literature showing an average eccentricity of 0.15 and an average inclination of 10°.

The origin of the asteroids is discussed in general terms as is the connection between the asteroids and meteorites. The physical properties of the asteroids are given but the limited amount of data which exists applies mainly to the four largest asteroids, Ceres, Pallas, Juno and Vesta. The measurements which are recommended are (1) visual measurements to detect the size, shape and nature of rotation of individual asteroids, (2) spectrometry and polarimetry to search for associated atmospheres and to examine surface features, (3) temperature measurements in the infrared and at microwave frequencies to observe in particular the terminator, (4) measurement of mass using a radar altimeter and monitoring the spacecraft perturbation, (5) magnetic field measurements in interplanetary space and through the asteroid belt, (6) plasma and charged particle measurements comparing intensities in and out of the belt and in the vicinity of individual asteroids, and (7) micrometeorite detection covering as wide a range of particle size and as large a volume of space as possible.

Author

AUTHOR

The data obtained from asteroid missions should be used to determine the mass distribution and hence the collision hazard in flying through the asteroid belt and to lead to an understanding of the origin and evolution of the asteroids. The missions which are briefly discussed could initially be coupled say with a Jupiter mission gaining particle and field data on the asteroids on the way. At a later stage landing on an asteroid will be possible when seismological, chemical and biological experiments can be performed and perhaps samples of asteroid material brought back to Earth.

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1. INTRODUCTION

The asteroids or minor planets orbit the Sun principally between Mars and Jupiter. More than 1500 separate bodies of magnitudes down to 18 have been detected and listed showing an average eccentricity of 0.15 and an average inclination of 10°, and all the observed asteroids rotate around the Sun in the same direction as the planets.

2. THE ORIGIN OF THE ASTEROIDS

Scientific speculation has provided numerous theories on the origin of the asteroids but these can be grouped into three basic mechanisms. The catastrophic origin associated with Chamberlin-Moulton, Jeans-Jefferies and more recently Lyttleton postulates a collision between two or more large bodies which were orbiting in agreement with Bode's law. The other two mechanisms postulate a more gradual formation at the same time as the solar system was evolving. The theory of Kant has been developed and refined by Laplace and Weisacker and more recently by Kuiper (1951), Urey (1952) and Rabe (1956). A gradual condensation involving only mechanical forces is desired and involving the asteroids with a 20:1 reduction in the proto-planet Jupiter to its present size. On the other hand Birkeland, Berlage, Dauville, and more recently Alfven (1954) would involve electromagnetic forces acting in a hot and fully ionized cloud in the condensation process.

After the formation of a number of bodies in the region of the asteroids it is generally agreed that subsequent collisions and fragmentation would occur with the average size of bodies being continually reduced. However support for the gradual condensation hypotheses would be provided if, as might be expected, any of the original condensations can be found in the asteroid belt. Support for this possibility has been derived from the magnitude versus frequency plot for the asteroids (Wood 1962) from which Kuiper has interpreted the separation of Ceres, Pallas and Vesta as representing a separate phenomena which may be due to them being original planetary condensations.

3. ASTEROIDS AND METEORITES

Meteorites have been falling to Earth for millions of years and offer analysts their only definite samples of extra-terrestrial matter. Attempts have been made to connect them with the Sun, the moon, the comets and interstellar space but evidence is accumulating to support an asteroidal origin. Three reasons can be quoted in support of this.

(a) Orbital data, particularly for Pribriam (1958), show the origin of meteorites to be in the asteroid region.

(b) They contain noble gases, He, A, Ne, Xe and therefore their quiescent temperature must have been less than 200 °K which is commensurate with a black body distance from the Sun greater than 1. 4 AU.

(c) The timing of meteorite falls bears no relation to the passage of comets or to meteor showers and the predominance of afternoon falls indicate that they overtake the Earth and therefore must have an orbit with a semi-major axis greater than 1 AU.

4. PHYSICAL PROPERTIES OF THE ASTEROIDS

Very little significant data exists on the physical properties of the asteroids mainly because they are relatively small objects when seen from Earth and in some case they pass rather quickly, hardly allowing time for orbital data to be obtained so that their next appearance can be predicted.

4.1 Mass

No mass or density information has been obtained for any asteroids.

4.2 Size

The first four asteroids (Ceres, Pallas, Juno, Vesta) have had their diameters estimated (770, 490, 193 and 386 km respectively) and probably for a further 20 the diameter would be detectable with a 200" telescope (Stumpf 1948).

4.3 Brightness

Ceres is the brightest asteroid (mag. 5) the others extending down to undetectable levels. Two types of information have been derived from photometric measurements.

(a) Periodic variations in brightness indicate irregular fragmental shapes (i. e. Eros 22 km x 6 km dia).

(b) Detailed examination of the light curves of asteroids yields data on their obliquity, rotation period and their poles. The asteroid poles appear to show some alignment (Gehrels and Owings 1962) but they have large, perhaps random obliquities (Kuiper et al 1958).

Prendergast (1958) has shown that the spin axis will align with the greatest moment of inertia in about 10^6 years. The rotational periods of asteroids range upwards from a few hours.

4.4 Albedo and Color

Again little information has been obtained on the albedo of the asteroids. The first four have albedos of 0.02, 0.07, and 0.12 and 0.26. (Stumpf 1948). Only minute color changes have been noted (Groeneveld and Kuiper 1954) and there is not sufficient data to correlate the color with the size of the asteroids.

4.5 Temperature

No data exists but black body radiation would give a subpolar point temperature of about 200°K.

4.6 Atmosphere and Surface

Comparative polarization measurements by Lyot (1929a, 1929b) show similarities between the moon, Mercury and Vesta indicating no atmosphere and a dusty meteoric surface. Danjon in Strasburg (1933) found the phase vs magnitude relation for the Earth, Mars, Venus and asteroids to be 0.156, 0.015, 0.015 and 0.028 magnitude change/degree phase, from which he deduced there was no asteroidal atmosphere. The supposed small mass of the asteroids should prevent retention of any significant atmosphere.

4.7 Structure and Composition

No data on the composition of the asteroids exist except insofar as meteorite analysis might be directly applicable to the asteroids.

4.8 Magnetic Field

No data on magnetic fields exists at all, although magnetic properties may have a significant influence on the formation of the asteroids. Data from planetary condensations would be very pertinent.

5. THE ASTEROID BELT

The mass distribution throughout the asteroid belt is unknown but Newburn (1961) suggests from observations that the smaller asteroids tend to occur further from the Sun. The asteroids have been grouped into families depending on their orbital parameters and the original five Hirayama families have been extended into 29 groups (Jaschek and Jaschek 1963). There are gaps between the families which coincide with harmonics of the Jupiter orbit indicating the general control Jupiter maintains over the asteroids.

5.1 Large Orbit Asteroids

The Trojans form a Lagrangian matrix with Jupiter (Watson 1956) having the same orbit (5.2 AU) but equidistant from the Sun and Jupiter. This is a stable position and 13 asteroids are known members of the group together with a possible further six. Rabe (1956) suggests, that with the protoplanet theory, the Trojans could originate in their present position only if the 20:1 reduction on the Jupiter mass occurred. Other distant asteroids of interest to the theories of origin are Thule (4.28 AU) and Hidalgo (5.79 AU the largest known orbit) both of which pass close to Jupiter.

5.2 Small Orbit Asteroids

Some of the asteroids which pass very close to the Earth (Hermes 8×10^5 km; Apollo 3×10^6 km; Adonis 1.5×10^6 km) were so fast in their perihelion passage that their orbits were not calculated and will only be found again by accident.

Eros ($a = 1.45$ AU, 0.24 eccentricity $T = 1.7$ years) is an interesting asteroid, being fairly bright and very irregular in shape. It can usually be observed for a few months on each orbit, and coming close to the Earth (2.3×10^7 km) offers a good chance of recovery.

Icarus ($a = 1.07$ AU $e = 0.82$) can pass within 5.7×10^6 km of the Earth. At perihelion it is the closest solid mass to the Sun (2.8×10^7 km). The study of Icarus as an object would be interesting to see the extended effect of its extreme environmental cycle.

Geographos ($a = 1.24$ AU $e = 0.33$) is a small asteroid (< 2 km dia) and approaches the Earth to within a mere 4.8×10^6 km. Its orbital inclination is 13° being about half that of Icarus and it may provide a much more amenable target.

5.3 Main Belt Asteroids

Within the main belt there are 15 asteroids larger than 100 miles dia and 9 more than 120 miles dia (Newburn 1961) including Ceres, Pallas and Vesta - the so-called planetary condensations. These large bodies should probably be the first asteroids to be investigated for evidence of their origin. The planetary condensations, and even Ceres, as the largest, are very small in size compared to the Earth and probably have not generated as high an internal temperature. It is likely that igneous processes have not aged the original matter to the same extent as in the planets (Wood 1962). Ceres has a semi-major axis 2.76 AU, a period of 4.5 yrs and an eccentricity of 0.076.

6. BASIC SCIENTIFIC QUESTIONS ON THE ASTEROIDS

The following questions are pertinent to the scientific understanding of the origin and the configuration of the asteroids.

6.1 Are there signs of original planetary condensations in the asteroid belt and can they be verified?

6.2 Is there an exclusive connection between the asteroids and meteorites?

6.3 What is the constitution of matter in the asteroid belt, (iron, stone, etc.) and how does this vary with the mass distribution?

6.4 What is the distribution of mass in the belt?

6.5 What is the density of asteroid matter? (mass and size)

6.6 Can fragmentation of larger bodies be proved?

6.7 What is the macroscopic construction of the asteroids? (accreted grains, entirely solid, silicate matrix with embedded nickel-iron etc.)

6.8 What is the nature of the surfaces? (dust covered, smooth etc.)

6.9 Can the age of asteroids be determined since fragmentation (cosmic erosion, radio activation etc.)

6.10 Is there any regularity in the rotations and obliquities of the asteroids?

6.11 What is the temperature of the asteroids? Is there any indication of internal heating?

6.12 Are there any signs of an atmosphere, present or past?

6.13 What magnetic fields are associated with the asteroids?

6.14 Is there any evidence for a biological history associated with the asteroids?

7. MEASUREMENTS

The following types of measurement are suggested in the region of the asteroid belt to determine answers to some of the above questions.

7.1 Visual Measurements (photography and TV)

High definition pictures of specific asteroids of interest would give information on their size, shape and rotations, and may reveal surface features. Panoramic scans from a spacecraft may indicate the mass distribution in the region of the probe.

7.2 Spectrometry and Polarimetry

Although light reflected from solids is sometimes difficult to interpret spectrally, any significant gaseous atmosphere could probably be seen. Polarization measurements will indicate the nature of the surface the existence of any surrounding dust cloud. Gamma ray spectrometry may yield information on the constitution of an asteroid providing the probe passed very close to it.

7.3 Infrared and Microwave Measurements

These will give data on the asteroid temperature and measurements across the terminator (if it can be seen on a fragment) will give cooling rates and hence surface information.

7.4 Mass Measurement

It may be possible to determine mass by monitoring the deflection of the probe in passing an asteroid and radar range measurements together with pictures will give the size and hence the density. The radar unit can be used to scan around the probe and plot the distribution of matter in at least one plane.

7.5 Magnetic Field

A sensitive magnetometer should be used to plot the magnetic field approaching and passing through the belt. Any localized fields due to asteroids should be recorded.

7.6 Charged Particle Experiments

Measurements of charged particles should proceed through the belt and comparisons with approach measurements should be made. Any trapped charges in the region of the larger asteroids should be registered.

7.7 Micrometeorite Detection

Measurements of the dust distribution should be made throughout the asteroid belt. This experiment can be phased in with the radar and photographic records to cover as wide a range of particle size as possible.

8. IMPORTANCE OF ASTEROID DATA

There are at least two aspects of scientific importance associated with the asteroid belt. The mass distribution, which is not known, may present a serious collision hazard for space missions to the outer solar system. Data revealing the origin of the asteroids and their relationship with the planets will provide supporting evidence for the origin of the whole solar system.

8.1 Mass Distribution in the Asteroid Belt

The mass distribution of the asteroids will provide data on the collision history of the belt but of equal immediate interest in the collision probability for a spacecraft either passing through the belt or even sent specifically to take measurements there. Particle mass and energy measurements will not be too difficult to obtain for micrometeoroids but will be subject to chance and hazard for larger masses. The results of such a series of experiments could be used to formulate the precautions necessary before direct penetration through the entire belt should be undertaken.

8.2 Origin of Asteroids

The asteroids may well be considered as secondary targets compared to the major planets but they have one important advantage in the information they can give on the internal structure of planet type material. The fragmentation of asteroids reveals cross sections of the structure of the original larger bodies, and although subject to aging by micrometeoroid collisions and sputtering, it may be possible eventually to theoretically reconstruct the originals. Further, since the bodies which are suspected of being original planetary condensations are much smaller than the planets, they may not have aged in the same way. The lower internal pressures and temperatures may well give information pre-dating that available from the planets. A factor of considerable significace to our knowledge of the solar system would be to derive data which would identify meteorites which were previously asteroids.

9. ASTEROID MISSIONS

The principal type of early measurements on the asteroids should concentrate on defining the mass distribution and collision cross section of the near ecliptic parts of the belt. Data should be obtained as far out as 5 AU if possible. Secondary experiments could then be fulfilled as offshoots of other major missions once the possibility of passing through the belt has been verified. Mass distribution, magnetic fields and surface properties would be of importance. One possibility is coupled with a Jupiter mission, where not only data passing through the main belt could be obtained, but by a suitable trajectory some of the Trojans may possibly be observed as they follow Jupiter in orbit.

The small mass of the asteroids makes it almost impossible to consider an orbit around an asteroid without a heavy investment in guidance power. However many asteroids have short periods of rotation which makes a 4π scan possible with a flyby mission. Ultimately detailed measurements must be made on individual asteroids, starting possibly with Ceres, and landings could be considered as providing seismological and biological information. The body could then be used for protection in solar investigations.

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